

Springer Tracts in Civil Engineering

Omoseni Adepoju  
Clinton Aigbavboa  
Nnamdi Nwulu  
Michael Onyia

# Re-skilling Human Resources for Construction 4.0

Implications for Industry, Academia and  
Government

 Springer

# **Springer Tracts in Civil Engineering**

## **Series Editors**

Sheng-Hong Chen, School of Water Resources and Hydropower Engineering,  
Wuhan University, Wuhan, China

Marco di Prisco, Politecnico di Milano, Milano, Italy

Ioannis Vayas, Institute of Steel Structures, National Technical University of  
Athens, Athens, Greece

**Springer Tracts in Civil Engineering** (STCE) publishes the latest developments in Civil Engineering - quickly, informally and in top quality. The series scope includes monographs, professional books, graduate textbooks and edited volumes, as well as outstanding PhD theses. Its goal is to cover all the main branches of civil engineering, both theoretical and applied, including:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering; Ocean and Offshore Engineering
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Heating, Ventilation and Air Conditioning (HVAC)
- Transportation and Traffic
- Risk Analysis
- Safety and Security

### **Indexed by Scopus**

To submit a proposal or request further information, please contact:


Pierpaolo Riva at [Pierpaolo.Riva@springer.com](mailto:Pierpaolo.Riva@springer.com) (Europe and Americas) Wayne Hu at [wayne.hu@springer.com](mailto:wayne.hu@springer.com) (China)


More information about this series at <http://www.springer.com/series/15088>


Omoseni Adepoju · Clinton Aigbavboa ·  
Nnamdi Nwulu · Michael Onyia


# Re-skilling Human Resources for Construction 4.0

Implications for Industry, Academia  
and Government

Omoseni Adepoju   
Faculty of Engineering and the Built  
Environment  
University of Johannesburg  
Johannesburg, South Africa

Clinton Aigbavboa   
Faculty of Engineering and the Built  
Environment  
University of Johannesburg  
Johannesburg, South Africa

Nnamdi Nwulu   
Department of Electrical and Electronic  
Engineering Science  
University of Johannesburg  
Johannesburg, South Africa

Michael Onyia   
Department of Civil Engineering  
University of Nigeria  
Nsukka, Nigeria

ISSN 2366-259X ISSN 2366-2603 (electronic)  
Springer Tracts in Civil Engineering  
ISBN 978-3-030-85972-5 ISBN 978-3-030-85973-2 (eBook)  
<https://doi.org/10.1007/978-3-030-85973-2>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# Preface

The fourth industrial revolution, also known as Industry 4.0, has transformed the construction industry by creating digital, smart and sustainable construction technologies. The innovative deployment of Industry 4.0 concepts and its application in the construction industry is called Construction 4.0. These new technologies such as Building Information Modelling (BIM), Robotics, 3D printing and Drones give the professionals in the industry a different outlook about optimising their operations to boost the delivery of cost-effective, timely and quality projects. The application of these technologies comes with several benefits and some risks. More importantly, the adoption of these technologies demand new skills for its operation and effective performance.

In order to realise the benefits of these modern technologies, the construction industry needs to address the inevitable challenges, especially those pertaining to human resources. The availability of required skills will improve the implementation of Construction 4.0 technologies. Consequently, it becomes necessary to develop and build talents for the present and future needs of the industry. In line with this, the stakeholders in the industry have roles to play in building the necessary capabilities required to rapidly adapt to the new technologies. The industry is responsible for training the workers, creating a learning environment for practical application of the new technologies and working closely with educational institutions to equip personnel with the required knowledge and skills for Construction 4.0. Also, educational and training institutions with the collaboration of the industry are required to design courses and training programmes that can help nurture, develop and re-skill the human resources suited for a digitalised construction industry.

Furthermore, the governments have a responsibility in policy formulation to reinforce human capital development both at the educational institutions and the workplace. Hence, this research book will examine the key technologies of Construction 4.0, the benefits, risks and relevant skills required to implement the technologies. The book will also consider human resources reskilling needs and the roles of key stakeholders in developing the skills needed for Construction 4.0. This research views

the lack of twenty-first century skills and the skills gap, especially in developing countries, as a limiting factor to implementing these technologies.

Johannesburg, South Africa  
Johannesburg, South Africa  
Johannesburg, South Africa  
Nsukka, Nigeria

Omoseni Adepoju  
Clinton Aigbavboa  
Nnamdi Nwulu  
Michael Onyia

# Contents

## Part I Introduction and Background to Reskilling and Upskilling for Construction 4.0 Technologies

<b>1 Introduction</b>	3
1.1 Background to the Study	3
1.1.1 Construction 4.0	4
1.1.2 Building Information Modeling (BIM)	5
1.1.3 Drones and Unmanned Aerial Vehicles	6
1.1.4 Prefabrication	7
1.1.5 3D Printing	7
1.1.6 Robotic Construction	8
1.1.7 Internet of Things (IoT)	9
1.1.8 The Need for Reskilling and Upskilling	10
1.2 Aims and Objectives	12
1.3 Organization of the Book	12
1.4 Contribution and Value	13
1.5 Summary	13
References	14
<b>2 Construction 4.0</b>	17
2.1 Introduction	17
2.1.1 Historical Background of Construction 4.0	20
2.1.2 Components of Construction 4.0	23
2.2 Prospects of Construction 4.0	31
2.2.1 Development of a Creative Environment	32
2.2.2 Improved Sustainability of the Construction Industry	32
2.2.3 Boosting of the Image of the Construction Industry	32
2.2.4 Increased Productivity	32
2.2.5 Reduction of Risk in Construction Sites	33
2.2.6 Enhanced Cost-Predictability	33
2.2.7 Saves Time	33
2.2.8 Improves Site Safety	33



- 2.2.9 Better Output for Worker’s Effort ..... 34
- 2.2.10 Growth in Foreign Trade Communication ..... 34
- 2.2.11 Increased Innovation in the Construction Industry ..... 34
- 2.2.12 Increase in National GDP ..... 34
- 2.3 Threats of Construction 4.0 ..... 35
  - 2.3.1 Reduced Creativity ..... 35
  - 2.3.2 High Start-Up Cost ..... 35
  - 2.3.3 Loss of Jobs ..... 35
  - 2.3.4 Increase in Social Anxiety Among Different Cadres ..... 35
  - 2.3.5 Cyber-Security Risk ..... 36
  - 2.3.6 Workers Enslavement ..... 36
  - 2.3.7 Increase in Unemployment ..... 36
  - 2.3.8 Increase in Expenditure of Import Materials ..... 36
- 2.4 Summary ..... 37
- References ..... 37

**Part II Construction 4.0 Technologies**

- 3 Building Information Modelling ..... 43**
  - 3.1 Introduction ..... 43
    - 3.1.1 Dimensions of Building Information Modelling ..... 44
  - 3.2 Application of Building Information Models in Construction ..... 48
    - 3.2.1 Design Visualization ..... 49
    - 3.2.2 Constructability Analysis ..... 49
    - 3.2.3 Site Planning and Utilization ..... 50
    - 3.2.4 Scheduling and Sequencing ..... 53
    - 3.2.5 Cost Estimation ..... 54
    - 3.2.6 Communication ..... 54
  - 3.3 Case Studies of Building Information Modeling Application  
in Construction and Resultant Benefits ..... 55
    - 3.3.1 Case Study One: Venetian Casino Construction  
in Macau, Hong Kong ..... 55
    - 3.3.2 Case Study 2: Cathay Pacific Cargo Terminal, Hong  
Kong ..... 56
    - 3.3.3 Case Study 3: Aquarium Hilton Garden Inn, Atlanta,  
Georgia ..... 57
    - 3.3.4 Case Study 4: National Cancer Institute (NCI)  
in Malaysia ..... 58
  - 3.4 Benefits of Building Information Models in Construction ..... 58
  - 3.5 Risk of Adopting Building Information Modelling ..... 60
  - 3.6 Relevant Skills Required for Building Information Modelling ..... 60
    - 3.6.1 Soft Skills ..... 61
    - 3.6.2 Technical skills ..... 62
  - 3.7 Summary ..... 62
  - References ..... 63

- 4 Drone/Unmanned Aerial Vehicles (UAVs) Technology** ..... 65
  - 4.1 Introduction ..... 65
    - 4.1.1 Components of a Drone ..... 67
    - 4.1.2 Classification of Drones ..... 69
    - 4.1.3 Types of Drones Used in the Construction Industry ..... 71
  - 4.2 Application Drone Technology in the Construction Industry ..... 74
  - 4.3 Case Studies of Drones/Unmanned Aerial Vehicles (UAVs) Technology Application in Construction and Resultant Benefits ..... 79
    - 4.3.1 Case Study One: 3D Building Construction in Shandong University of Science and Technology and the Henan University of Urban Construction ..... 79
    - 4.3.2 Case Study Two: Projects A (91 5-Story Buildings and 5 3-Story Buildings), and Project B (1 26-Story Building) ..... 80
  - 4.4 Benefits of Drones/Unmanned Aerial Vehicles Application in Construction ..... 82
  - 4.5 Risks Associated with Drone Technology ..... 84
  - 4.6 Skills Required for Drone Operation in the Construction Industry ..... 85
  - 4.7 Summary ..... 87
  - References ..... 87
  
- 5 Prefabrication** ..... 91
  - 5.1 Introduction ..... 91
    - 5.1.1 Classification of Prefabrication ..... 92
  - 5.2 Application of Prefabrication in Construction ..... 100
    - 5.2.1 Residential and Commercial Housing ..... 101
    - 5.2.2 Reconstruction of Bridges and Rehabilitation ..... 102
    - 5.2.3 Stadiums and Grandstands ..... 103
  - 5.3 Case Studies of Prefabrication Application in Construction Projects and the Resultant Benefits ..... 105
    - 5.3.1 Case Study One: Fort Sam Houston Medical Education and Training Complex ..... 105
    - 5.3.2 Case Study Two: One9 Modular Building in Melbourne Australia ..... 105
    - 5.3.3 Case Study Three: La Trobe Tower in Melbourne, Australia ..... 106
  - 5.4 Benefits of Prefabrication Application in Construction ..... 107
  - 5.5 Risk of Adopting Prefabrication in Construction ..... 110
  - 5.6 Relevant Skills for Prefabrication Application ..... 111
  - 5.7 Summary ..... 113
  - References ..... 114

<b>6</b>	<b>3D Printing/Addictive Manufacturing</b>	117
6.1	Introduction	117
6.1.1	3D Printing Materials	119
6.1.2	Methods of Three-Dimensional (3D) Printing Technologies in Construction	121
6.2	Application of 3D Printing to Construction	125
6.2.1	3D Architectural Design	125
6.2.2	3D Printed Houses	126
6.2.3	3D Office	126
6.2.4	3D Bridge and Canal	127
6.2.5	Stormwater Collectors	129
6.3	Case Studies of 3D Printing Applications in Construction Projects and Resultant Benefits	130
6.3.1	Case Study One: Apis Cor Printed House in Russian	130
6.3.2	Case Study Two: 3D Printed Office in Dubai	130
6.3.3	Case Study Two (3): Freeform Truss Shaped Pillar in Aix-En-Provence, France	131
6.3.4	Case Study Four (4): Ten (10) 200 Square Meters Houses in China	131
6.4	Benefits of 3D Printing Addictive Manufacturing in Construction	131
6.5	Risks Associated with 3D Printing in Construction	133
6.5.1	Health Risk	133
6.5.2	Cyber Risk and Intellectual Property Risk	134
6.5.3	Legal and Regulation Risk	134
6.5.4	Risk of Job Loss	134
6.5.5	Management Risk	135
6.5.6	Material Shortage Risk	135
6.5.7	Financial Risk	135
6.6	Skills Requirement for 3D Printing Application in Construction	136
6.6.1	Technical Skill	136
6.6.2	Software Designing Skill	136
6.6.3	Modelling Skill	137
6.6.4	Creativity Skill	137
6.7	Summary	137
	References	138
<b>7</b>	<b>Robotic Construction Technology</b>	141
7.1	Introduction	141
7.1.1	Components of a Robot	143
7.1.2	Types of Robotics Construction	144
7.2	Application of Robotic Technology in Construction	146
7.2.1	Painting and Spraying	147
7.2.2	Demolition	148

- 7.2.3 Bricklaying and Plastering ..... 149
- 7.2.4 Construction Welding ..... 153
- 7.2.5 Transportation in Construction ..... 154
- 7.2.6 Surveying and Monitoring ..... 155
- 7.2.7 Roadwork ..... 156
- 7.2.8 Interior Decoration ..... 156
- 7.3 Case Studies of Robotic Construction Applications  
in Construction Projects and Resultant Benefits ..... 159
- 7.3.1 Case Study One: Semi-Automated Mason (SAM  
or SAM100) ..... 159
- 7.3.2 Case Study Two: Jay and Susie Gogue Performing  
Arts Center Rendering ..... 160
- 7.4 Benefits of Robotic Construction Application ..... 161
- 7.5 Risks Associated with Robotic Construction ..... 162
- 7.6 Relevant Skills for Robotic Construction ..... 163
- 7.6.1 Computing Skills ..... 164
- 7.6.2 Computer Science Skills ..... 165
- 7.6.3 Soft Skills ..... 166
- 7.7 Summary ..... 167
- References ..... 168

- 8 Internet of Things (IoT) ..... 171**
- 8.1 Introduction ..... 171
- 8.1.1 Components of Internet of Things ..... 173
- 8.1.2 Technologies of Internet of Things ..... 175
- 8.1.3 Architecture Layers of Internet of Things ..... 177
- 8.1.4 Communication/Connectivity Models for Internet  
of Things ..... 178
- 8.2 Applications of Internet of Things to the Construction Industry .... 180
- 8.2.1 On-Site Applications ..... 181
- 8.2.2 Off-Site Construction Buildings Applications ..... 185
- 8.3 Benefits of Internet of Things in the Construction Industry ..... 187
- 8.4 Threat Associated with IoT in the Construction Industry ..... 189
- 8.5 Relevant Skills for the Internet of Things ..... 191
- 8.6 Summary ..... 192
- References ..... 193

**Part III Reskilling and Roles of Stakeholders for Implementation  
of Construction 4.0**

- 9 Reskilling for Construction 4.0 ..... 197**
- 9.1 Introduction ..... 197
- 9.2 Concept and Significance of Skills ..... 198
- 9.2.1 Soft Skills ..... 199
- 9.2.2 Hard Skills ..... 199
- 9.3 Current Skills Demand for Construction 4.0 ..... 199

- 9.3.1 Building Information Modelling ..... 200
- 9.3.2 Drone/Unmanned Aerial Vehicles (UAVs) Technology ..... 200
- 9.3.3 Prefabrication ..... 201
- 9.3.4 3D Printing/Addictive Manufacturing ..... 201
- 9.3.5 Robotic Technology ..... 201
- 9.3.6 Internet of Things (IoT) ..... 202
- 9.4 The Concept of Reskilling and Upskilling in the Fourth Industrial Revolution ..... 202
  - 9.4.1 Reskilling ..... 203
  - 9.4.2 Upskilling ..... 204
  - 9.4.3 Need for Reskilling and Upskilling in Construction 4.0 Era ..... 204
  - 9.4.4 Importance of Upskilling and Reskilling ..... 205
  - 9.4.5 Strategies for Reskilling and Upskilling for Construction 4.0 ..... 207
- 9.5 Role of Industry, Academia and Government in Reskilling for Construction 4.0 ..... 209
  - 9.5.1 Role of Construction Industry in Reskilling and Upskilling ..... 210
  - 9.5.2 Role of Educational Institutions ..... 212
  - 9.5.3 Role of Government ..... 214
- 9.6 Framework for Reskilling for Construction 4.0 ..... 216
- 9.7 Summary ..... 218
- References ..... 219

**Part I**  
**Introduction and Background to Reskilling**  
**and Upskilling for Construction 4.0**  
**Technologies**

# Chapter 1

## Introduction



### 1.1 Background to the Study

The construction industry, a significant driver of economic growth of nations, is currently experiencing transformation through advancements in technology ushered by the fourth industrial revolution, also known as Industry 4.0. This transformation is demanding new approaches and specific skills requirements for effective implementation. This revolution is significant as the construction industry represents an economic booster and a major source of employment opportunities. This is also reflected in the 2018 analysis of McKinsey, which reveals that global spending in the construction industry was \$11 trillion, with a projection to \$814 trillion in 2025, accounting for 9% of World GDP. In sub-Saharan Africa, the construction industry market is projected to register a 6.4% CAGR by the end of 2024 (Africa Review, 2021). An observation of the built environment and humans' daily activities reveals that the construction industry shapes humanity's economic, social, and environmental aspects.

Industry 4.0 is premised on combining physical and digital technologies with data, cyber-physical systems and the Internet of things (IoT) in ensuring smart production and processes. The cyber-physical system, which is the core of the fourth industrial revolution, comprises a pair of technologies that connect the physical and virtual worlds. These technologies can create an intelligent environment where smart objects communicate and interact with one another. The technologies of industry 4.0 include the Internet of Things (IoT), Big Data, Augmented and Virtual Reality, Simulation, cybersecurity, Cloud computing, Robotics, Prefabrication/Additive manufacturing and integration of Horizontal and Vertical systems. These nine (9) pillars have reshaped, reprogrammed and refocused the process, technologies, and methodologies, of many industries, such as the Construction industry. Industries can be assured of operational efficiency, optimised profitability, better quality, increased productivity, customer and stakeholder satisfaction, and more innovations.

Industry 4.0 technologies exert influence and pressure on other industries, especially the construction industry, which is the fulcrum of humanity. The influence of

industry 4.0 technologies on the construction industry is known as construction 4.0. The construction industry Fourth Industrial Revolution is the application of industry 4.0 in the construction industry (Adepoju & Aigbavboa, 2020). Construction 4.0, according to Sawhney et al. (2020), is “*a paradigm that uses cyber-physical systems, and the internet of things, data and services to link the digital layer consisting of BIM and Common Data Environment (CDE) and the physical layer consisting of the asset over its whole life to create an interconnected environment integrating organisations, process, and information to efficiently design, construct and operate assets*”. Construction 4.0, as adapted from industry 4.0 technologies, is the application of emerging technologies, digital processes and cyber-physical procedures to construction activities in the industry. The Fourth industrial revolution in the construction industry is a new dawn of processes driven by digital technologies permeating the architectural, engineering, construction and facility management of the construction industry.

Moreover, construction 4.0 operates on four (4) design principles of interconnection and interoperability, technical assistance (seen in the usage of drones, robots, 3D printing), Information transparency (occasioned by virtual reality and augmented reality in construction processes) and decentralised decision making (Hossain & Nadeem, 2019). Hence, construction 4.0 brings about digital clarity in construction procedures and automated processes in construction activities. The application of Industry 4.0 to Construction can be summarised under six principles which include: virtualisation, decentralisation, modularity, service orientation, interoperability and real-time capability (Hermann, Pentek, & Otto, 2016). Virtualisation is the ability of devices with the use of sensors to monitor physical procedures and communication between machines. The principle of decentralisation entails decentralised decision making empowered through computer systems installed for devices, workers and organisations. Modularity entails establishing a modular manufacturing system, which creates manufactured components that can be assembled, expanded, flexible, and replaced. The principle of service orientation emphasised that the technologies must solve problems and satisfy needs and wants. Interoperability is the ability of technologies to connect, communicate with each other and comprehend the functionality of one another. Real-time capability entails the immediate collection, transmission and analysis of data required by machines and men for effective operations and decision-making processes.

All these principles and models of the fourth industrial revolution have shaped both the construction industry, demanding an adjustment to new ways of building construction projects, new ways of living inside construction projects, and new ways of maintaining finished projects.

### **1.1.1 Construction 4.0**

Construction 4.0 revolves around creating a digital construction site through internet-connected sensors on equipment and its application at modern technologies at



every stage of the construction project (Osunsanmi, Aigbavboa & Oke, 2018). This concept has introduced several changes in the construction industry, such as the application of industry 4.0 technologies, mass production, green Construction, increase in professional technological proficiency and customisation. The Construction 4.0 technologies include: Building information modelling (BIM), Big data, Internet of things and services, unmanned aerial vehicle (UAV), additive manufacturing (3D printing), modular prefabricated Construction, 3D scanner, cloud computing, Augmented reality (AR)/ Virtual reality (VR)/ Mixed Reality (MR), simulations of virtual robotics/ autonomous vehicle, GPS, Artificial intelligence, sensors and actuators, cyber-physical systems and Radio-Frequency Identification (RFID) (Kozlovska, Klosova & Strukova, 2021). Most of this technology is infused in the construction industry during application in construction activities. The most prominent Construction 4.0 technologies are Building Information Modeling (BIM), Drones and Unmanned aerial vehicles (UAC), prefabrication, 3D printings, Robotic Construction and the Internet of things. The effective implementation and utilisation of these technologies require specific skills and a technologically oriented environment. However, this book explored six major Construction 4.0 technologies in the construction industry. These are discussed below:

### ***1.1.2 Building Information Modeling (BIM)***

The construction industry optimises the construction data and information through building information modelling (BIM). According to Mohandes and Omrany (2013), the BIM is a project simulation technology consisting of three dimensional (3D) models of project components by connecting all the project data and information to the project planning, project constructing and decommissioning. The US National Institute of Building Sciences (2007) defined the BIM as “*a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decision making during its life cycle, defined as existing from earliest conception to demolition*”. According to Tahir et al. (2017), the BIM technology applications in the construction industry includes design and visualisation, scheduling, quantity take-off and estimation, quality and risk control, integration and collaboration of stakeholders, clash detection and coordination, analysis of constructability, material resource control, human resource management, facility management, reduction of reworking during Construction, contract administration and efficient communication. The BIM is an integrative technology that collects and use construction stages. Mohandes and Omrany (2013) opined that BIM is very important to the construction industry due to its numerous benefits, such as improvement in project visualisation, proper team management, analysis of complex details, effective project scheduling, estimations of work breakdown structure, quick site preparations, enabling the best routes for pipes, lights, cables, wires, ductwork and sprinklers; proper scheduling for lifts for the utilisation of concrete, steel, electrical equipment placement and huge mechanical

equipment placement, evaluation of needed safety precautions and adequate coordination of construction activities. This unequivocally improves construction works, site effectiveness, waste reduction and management, cost-effectiveness and high project performance. The BIM technology is built with various software, including Revit, Revizto, Navisworks, ArchiCAD, Vectorworks Architect, Edificius, Autodesk BIM 360, Sketchup, Buildertrend, BIMobject, Civil 3D, BricsCAD BIM, Sefaria, VisualARQ, AllPlan Architecture, ActCAD BIM (Ocean, 2020).

### ***1.1.3 Drones and Unmanned Aerial Vehicles***

Construction works are often complex, depending on the project size or nature of the project site. However, for efficiency, drones which happen to be one of the industry 4.0 technologies, can be utilised. Drones, also known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS), are like an aircraft without anybody controlled from a remote place. Drones are equipped with downward-facing sensors such as LIDAR, RGB for capturing aerial data in a short time (Wingtra, 2021). Tkac and Mesaros (2019) opined that the utilisation of drones in the construction industry had served many purposes, which includes: inspection of highways, bridges, cell towers, wind turbines, high mast lighting, building façade, surveying and mapping, drainage and erosion, traffic monitoring and wetland. Drone usage in construction 4.0 is mainly for data collection and monitoring purposes. In collecting and collating data from the built environment and construction sites, drones can access and navigates narrow and dangerous locations. The high-quality data collected through drones have helped in construction management in the following areas of site coordination, safety, dispute resolution, quality control, planning and designing documentation of field conditions, the performance of large scale analysis, time management, cost efficiency, aiding better project performance, building surveys, laser scanning and aerial photogrammetric for scanning buildings, thermal image recording for assessing cold spots in buildings (McCoy & Yeganeh, 2021; Tkac & Mesaros, 2019). According to Tkac and Mesaros (2019) and Chapman (2013), different types of Drones are used for construction works, and these include: multi-rotor drones (primarily used for aerial mapping, aerial photography, aerial surveying and video recording); fixed-wing drones, ( high altitude drones, used for efficient for aerial mapping topography); single rotor drones (drones with one rotor but last longer in the air than multiple rotors), and fixed-wing hybrid, vertical takeoff and landing rotor (a drone that flies on a pre-scheduled flight route at user-specified heights and collects data through its colour and multispectral sensors).

### ***1.1.4 Prefabrication***

Ineffective material management has been a constant headache for construction professionals, as materials are the cornerstones of a construction project. This is why prefabrication technology has been adopted. It entails producing construction components off-sites and then assembled on-site to create/ build the needed structure. According to Li et al. (2014), prefabrication entails producing various construction components at a specialised facility before final assembling and installation. This process is against conventional construction processes of the cast-in-place of concrete, timber formwork, bamboo scaffolding, tilling, reinforcement, and plastering. Auti and Patil (2018) opined that prefabrication technology is the construction process that entails: the finalisation of the design of various components of casting, structure and curing of units, transportation of units on site and the installation of those units. Mays (2021) stated that advantages of prefabricated technology include: a reduction in labour costs, improvement in labour safety, minimisation of construction delays, increase in high quality of work, sminimisation of waste, increases paces of work and increase in energy efficiency.

### ***1.1.5 3D Printing***

Another construction 4.0 technology is 3D printing, a digital fabrication technology that produces physical object 3D printing. This digital fabrication technology produces physical objects in a dimensional structure of any shape from a geometrical representation (Shahrubudin, Lee, & Ramlan, 2019). Also, Hossain et al. (2020) stated that 3D (three dimensional) printings, which is industrially known as additive manufacturing, are an automated process that produces 3D shapes using a computer-aided design (CAD) on a layer by layer basis to get the required results. The use of 3D printing technology in the construction industry, which is enhanced by other construction software, is more about the precision of buildings and buildings parts coupled with time effectiveness. Also, in 3D printing, different materials are integrated to print a particular building layer, such as binders, cement, sand, aggregate, and water. 3D printing layers are primarily manufactured and produced off-site before being assembled on the construction site. In the construction industry, the 3D printing technology aids the reduction of a manual process, reduce construction waste by 30–60%, construction time by 50–70%, labour costs by 50–80%, material costs by 65%, and it is environmentally friendly (Markets & Markets, 2020; Hossain et al., 2020; Allouzi, Al-Azhain & Allouzi, 2020). 3D printing is enabled by 3D printers, which includes stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling, FDIM (Formlabs, 2021). Other printers, according to Cherdo (2021), includes; BetAbramPi, COBOD BOD 2, 3D constructor, Cyber construction, ICON Vulcan II, MudBots 3D concrete printer, Total Kustom story Bot 6.2, WASP Crane WASP, APIS cor, Bati print 3D, SQ4D—ARCS, Contour crafting

and Xtree E. However, before 3D printings, they are designed in several 3D software, depending on construction requirements. These include Sketch-up, AutoCAD, ArchiCAD, AutoCAD Architecture, DataCAD, Revit, Cedreo, Auto CAD Civil 3D, chief Architect, All plan Vectorworks Architect, Microstation, Bricscad BIM, Rhino 3D, CorelCAD, Solid works (Sculpteo, 2021).

### ***1.1.6 Robotic Construction***

Consequently, like most industries, data and information are the operational bedrock of the construction industry. This data feeds into different construction processes and technologies to optimise the satisfaction of end-users and maximise shareholders' wealth.

Moreover, construction activities, processes and procedures require excessive human efforts to achieve project performance, which has led many stakeholders and investors to use automation through Robotics for efficiency and effectiveness. Robotic technology is a technology designed to replace and perfect some human activities and work. Umachandran (2020) stated that Robotics technology is an interdisciplinary field of information engineering, computer science and electro mechatronics to compute and control using sensory feedback and dispensation of data to support applications that substitute human actions. McCoy and Yeganeh (2021) also stated that construction robotics entails the design, construction, operation and application of robots at the different levels of components, building and infrastructure. Turner et al. (2021) opined that Robotics in the construction industry is applied using unmannered aerial vehicles and quadruped robots. Also, robotics is used in various ways, such as surveying construction sites, gathering data for 3D building modelling, and aiding workers in carrying heavy tool kits. Robots, through various computer programming, can be used for painting, bricklaying, loading using an autonomous vehicle without an operator, and acts as technical assistant to construction manager and workers. Robots are both use off-site and onsite, where off-site applications include the production of concrete, brickwork or steel components. In contrast, the onsite applications include reinforcement manufacturing and positioning, steel welding, distribution of concrete, façade operations, earthmoving and material handling (McCoy & Yeganeh, 2021). The use of Robots in the construction industry brings about: time efficiency, accessibility and decentralisation of information, aids mobility, improves workers' performance, efficient site management, cost-effectiveness, automation of excavation, drilling, earthworks, precision and accuracy, and increment in productivity. However, there are different kinds and types of robots used in the construction industry, which depends on the task for which it is built. Examples are road bricklaying robots, demolition robots, welding robots, painting robots, humanoid robots, exoskeleton suits robots, forklift robots, contour crafting robots, etc. According to Das (2021), typical robots must exhibit five major fields. The five major fields are: operator interface (a medium of communication between the user and the robots); mobility (that is, it must be able to move, and this

is usually designed based on human anatomy), manipulators and effectors (that is the ability of the robots to interact with the environment in moving and picking objects according to commands); programming (this the language inputted into the robots to give commands, allowing it to adapt and learn changes in the environment) and Sensors (the ability of the robot to sense and gather data from the environment using sensors). Robotic technology is a construction 4.0 technology that is bringing about change in the construction industry landscape, construction activities, processes and construction management.

### ***1.1.7 Internet of Things (IoT)***

Internet of things is an ecosystem of the Internet, where the Internet is the connector between things and things, people and people and also things and people. Umachandran (2020) stated that IoT technology is an integrated computing device through the attachment of sensors to machines, devices and gadgets for data collection and analysis, situation monitoring and recording. The main backbone technology in the IoT system is Radio Frequency Identification (RFID), which consists of a radio transponder, radio receiver and transmitter to automatically identify and track tags attached to objects, gadgets, machines or equipment.

Moreover, Turner et al. (2021) opined that IoT devices use different communication protocols for sending and transmitting data with different frequencies and ranges. These protocols are; Bluetooth with 2.4 GHz frequency and 50–150 m; Zig Bee 3.0 protocol of 2.4 GHz within 10–150 m; Wifi of 2.4 GHz and 5 GHz band with approximate 50 m; LoRaWAN of different frequency and between 2 and 15 km and also cellular protocols, with a frequency of 900/1800/1900/2100 MHz and with ranges of 85 km (GSM) and 200kkm (HSPA). Furthermore, McCoy and Yeganeh (2021) stated that the IoT technologies, in collaboration with other technologies in construction 4.0, are applied to: monitor and control the progress of construction projects, identify real-time material and equipment location, monitor workers health, knowledge of the material quantity, observe the conditions of equipment on-site and monitoring of vibration, deformation, tensile stress, comprehensive stress, temperature and wind speed in construction sites.

The technologies of construction 4.0 are efficiency optimisers for the Construction industry, which will help shape all aspects of construction activities. Sawhney et al. (2020) stated that adopting Construction 4.0 technologies in the construction industry would solve productivity stagnancy and low efficiency facing the industry. Also, Turner et al. (2021) opined that construction 4.0 technologies adoption in the industry would lead to efficient utilisation of natural resources, reduced life cycle, costs of construction projects and reduction in greenhouse emission. Qureshi et al. (2020) stated that construction 4.0 would solve the construction industry's long-standing challenges of conflict in scheduling, cost/ budgets overruns and construction risk management. Hossain and Nadeem (2019) opined that the digitalisation of the construction industry would introduce: improvements in construction designs,

quality enhancements of construction projects, and efficient digitalisation of the construction industry value chain. Osunsanmi et al. (2018) stated that the adoption of Construction 4.0 technologies would have the following advantages: the creation of a sustainable building, speedy budget project delivery, enhancement of safety, facilitation of harmonious relationship between professionals, adequate construction planning, effective monitoring and controlling, encourage seamless communication throughout the organisation, promotes the participation of employees in the decision making process, reduction of errors and rework, and overall ensure client satisfaction. Unequivocally, the adoption and usage of Construction, 4.0 technologies in the construction industry and the built environment will lead to: a sustainable environment, high rate of project success, cost-effective construction projects, minimisation of waste, improvement in safety management, assurance of quality at all stages of construction, enhanced time performance and schedule, aid more innovations breakthrough in the industry, improved workers productivity, increase the life cycle value of buildings and construction projects, effective data management and analytics, helps in the attainment of the United Nation 2030 sustainable development goals and increase construction industry contribution to a nation's economic growth and development.

### ***1.1.8 The Need for Reskilling and Upskilling***

However, the benefits, importance, features, and advantages of Construction 4.0 technologies adoption in the construction industry have placed an enormous demand on skill development in the industry since the industry is an epochal transition. Adepoju and Aigbavboa (2021) and Alaloul et al. (2019) stated that these technologies would lead to skill disruptions altering skills, practices and approaches in the construction industry. Also, this disruption will lead to the loss of thousands of jobs, as the technologies of construction 4.0 will replace human labour. According to Adepoju and Aigbavboa (2020), the digitalisation of construction work comes with several benefits and opportunities despite its challenges, such as the loss of jobs. The benefits and opportunities identified are: advancements in productivity of employees, promotion of job satisfaction among workers, reduction in construction risks for workers, reduction in the number of hours required for a worker, reduction in accidents and loss of lives, workers access to current project information and team management.

Nevertheless, the challenges and opportunities ushered by construction 4.0 technologies are a research gap in skill development in upskilling and re-skilling in the construction industry, which is the book's focus. Slowey et al. (2019) and Cerika and Maksumic (2017) also emphasised the opportunity of skill acquisition and development in creating a skilful, better and creative workforce for the industry. Also, Ras et al. (2017) opined that technology usage in industry 4.0 would lead to a shift and upgrade of job profiles, which might be challenging since most needed skills are more interdisciplinary. Manda and Backhouse (2017) stated that the new technologies in the industry require a new breed of innovative and technologically savvy workers.

Vuyiswa and Nischolan (2019) noted that the new required skills would include: analytical thinking and innovation; active learning and learning strategies; creativity, originality and initiative; technology design and programming; critical thinking and analysis; complex problem solving; leadership and social influence; emotional intelligence; reasoning, problem-solving and creativity; and system analysis and evaluation. According to a McKinsey report, more than 371 Million workers might need to change their levels and type of skills by the year 2030 due to the digitalisation of various industries (Chakma & Chaijinda, 2020). The required skills are technical and soft skills for utilising each of the technologies in the industry, which will lead to a wide skill gap in the construction industry. Adepoju & Aigbavboa (2021) averred that the skill gap entails the differences in the current level of skills in an organisation or industry and the future skills needs of the organisation. This is currently happening in the construction industry before the advent of construction 4.0, where employers cannot find the required work with the right skill in the labour market even in developed and developing countries (Juricic, Galic & Marenjak, 2021). However, in bridging this skill gap created by construction 4.0, there is a need for re-skilling and upskilling, which construction stakeholders and professionals must support across the industry.

According to Sivalingam & Manson (2020), re-skilling means learning an entirely new skill which leads to a new job profile and career position while upskilling is learning new skills that will improve the current job profile. Also, as stated in Chakma and Chaijinda (2020), the Cambridge dictionary describes re-skilling as an attempt made “*to learn new skills so that you can do different jobs*” and upskilling means “*to learn new skills or to teach workers new skills*”. Therefore, with construction 4.0 technologies in the construction industry, construction workers and professionals must adapt quickly to the mechanism of upskilling and re-skilling of skills in the industry to match the expected Construction 4.0 technical and soft skills. This is necessary to avert the loss of an experienced and knowledgeable construction workforce.

Consequently, in re-skilling and upskilling of skills in the construction industry in line with construction 4.0 technology, there is need for a collaborative though separated efforts of construction industry stakeholders, including the industry, academia and the government, in the form of a skilled supply chain. Through various construction companies, the industry must begin to see re-skilling and upskilling of their workforce (through training and retraining) as an investment into organisational growth and sustainability. Construction companies must start to give skill training a priority by ensuring their professionals and workers attend required courses, conferences, symposiums, and events that will re-skill and upskill them in line with the skills needed for construction 4.0. Also, construction companies should adopt the mechanism of interdepartmental and Intra-organisational partnership for appropriate knowledge and skill transfer, thus helping them in re-skilling and upskilling their workforce. However, as the industry through construction companies and bodies shapes the current workforce in line with construction 4.0 required skills, academia has a two-way approach to help in re-skilling and upskilling in the construction industry. Firstly, academia must rejig curriculum in the built environment to suit